SOME EXPERIMENTS ON FLAME

IN December 1881 my attention was casually called to the popular superstition that sunlight puts the fire out. Returning from a walk I had found the blinds of my sitting-room closely drawn, for the benefit, as I was told, of the fire, which was low. On my appearing somewhat sceptical about the use of this proceeding, my landlady cited the above-mentioned superstition as a well known fact. For her benefit and instruction I made the poker red hot, and focused the sun's rays on it with a bull's-eye, showing her that, though the bright light prevented the red heat from being seen, it had not extinguished it, and was, moreover, capable of making a smaller piece of metal red hot. But I was myself so struck with the power of even the December sun in overcoming the light of the most highly incandescent body, that I determined to make further experiments. Even the intense glow produced by heating in the blowpipe flame a small piece of chalk, though it was sufficient to light up the whole room, entirely disappeared in the sun's rays. This led me to ask what would be the result of testing the sun's light in the same way against that of a flame. If, according to the older theory, luminous flame consists of incandescent solid particles, then I should expect that these would behave under the strong light exactly as the white-hot iron did, while, on the other hand, if as some have maintained the white light of a flame proceeds from gases of great vapour-density, then I might expect results which, if not different, would be at least interesting.

Experiment I.—Accordingly, on December 7, 1881, I arranged my large condenser—a lens 5 inches in diameter, and 20 inches focus—so as to throw the image of the sun upon the flame of a paraffin candle. To my delight a round spot of light of a bluish-white colour and peculiar soft appearance was visible on the flame itself. That the flame, whether gaseous or consisting of incandescent particles, could reflect light, was certain. It remained for me to determine the characteristics of this reflection. From its colour and peculiarly "soft" appearance it reminded me of fluorescence. I therefore proceeded to test the question with the spectroscope.

Experiment 2.—I examined first the spectra given when a beaker of petroleum or one of solution of quinine sulphate was placed in the focus. I should mention that my spectroscope, which I designed and made myself, slides up and down the supporting pillar, so that it can be adjusted to any height. The table carrying the slit, and telescope, and prism (dense flint of 60°), can be fixed in three positions to the stand, so that the slit may be vertical, horizontal, or directed vertically downwards for examining solutions with the light thrown up from beneath. It is also provided with a doublet, equivalent to the B eye-piece of a microscope, used as a condenser to throw the image, which may be an enlarged or diminished one at pleasure, of any object upon the slit. The whole arrangement is very simple, and far more convenient than that of the ordinary laboratory spectroscope. Bringing the instrument thus armed to bear upon the strongly illuminated solution, I found the field of view to be filled with a soft and even light, that seemed to obscure the Frauenhofer lines as if some thickened luminous solution had been poured over them. Every moment some particle of dust floating into the focus would cause a tiny flash as its image crossed the slit, of hard clear light, like that of the candle-flame, only that it showed the Frauenhofer lines. But after filtering the solution, carefully cleaning the beaker, and excluding all extraneous light, the Frauenhofer lines vanished, and nothing was visible either with quinine or petroleum but the soft continuous spectrum of fluorescence. I have described these well-known phenomena thus minutely that I may emphasise the very different results obtained in the following experiment. To the naked eye the spot of sunlight upon the candle-flame was of exactly the same soft quality, and nearly the same colour as that upon the fluorescent solution. I replaced the candle in the focus, arranged the condenser of the spectroscope so that the white spot should come upon the centre of the slit, and occupy one-third of it. The field of view was filled by the spectrum of the flame, but across the centre was a bright band of light extending far into the violet, brightest in the blue, and showing *all the Frauenhofer lines distinctly*, especially in the blue and violet. Unmistakably I was dealing with reflected light, and not with fluorescence. My thoughts at once reverted to Prof. Tyndall's "blue cloud." I knew of two ways of producing an extremely fine precipitate showing the same characteristic phenomena. I added dilute hydrochloric acid to a weak solution of sodium hyposulphite, but this preparation I found to be troublesome from the rapidity with which it loses its optical properties, so I discarded it in favour of the following. I diluted some French polish with about fifty times its bulk of methylated spirit, and added a few drops of the solution

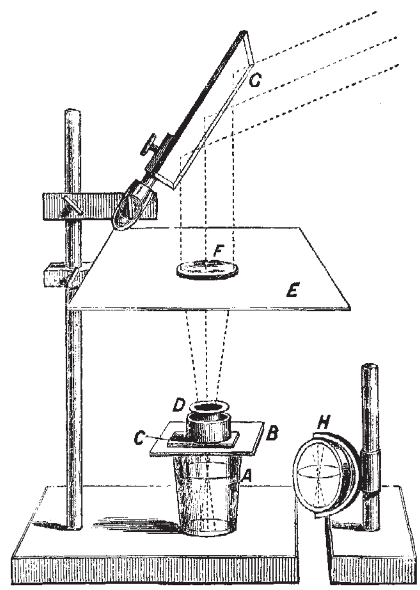


FIG. 1.—A, tumbler containing "lac precipitate"; B, glass plate to support polarising apparatus; C, selenite film; D, polarising prism; E, sheet of cardboard to screen off superfluous light; F, lens to concentrate the light; G, mirror; H, side mirror in which the colour of the beam in a different azimuth may be seen.

to a glass of water. The precipitate of lac resulting is sufficiently fine for every purpose, and will remain in suspension for days. The light from the heliostat passing through this solution gives the same soft opalescent reflection, with the same spectrum strongest in the blue and violet, showing all the Frauenhofer lines distinctly, as it does upon the candle-flame.

Experiment 3.—There is another special characteristic of matter in extremely fine division common to Prof. Tyndall's "blue cloud" and the above-mentioned solutions. Light reflected from it is completely polarised in the plane at right angles to the line of incidence. I am in the habit of showing this by the following arrangement, which I believe to be new, and which is so simple that any one can exhibit it. It is shown in Fig. 1. A is an ordinary plain tumbler, half filled with "lac precipitate," and covered with a piece of window-glass, B. On B is laid a mounted selenite film, C, and upon this again the polarising prism D, used with the microscope. A retort-stand supports a sheet of cardboard, E, with a hole in the centre, which shades the liquid from superfluous light

and also carries a lens, F, which may be an ordinary eye-glass laid across the hole, and so adjusted that its focus shall come about the middle of the liquid. A plane mirror, G—a hand-glass will do—is then either held or fixed, so as to reflect sunlight perpendicularly upon the lens. It will readily be seen that the light, concentrated by the lens, is plane-polarised by the Nicol prism, then modified by the selenite, and finally analysed by reflection from the extremely minute particles of lac. Accordingly, to a person walking round the table with his eye on a level with the tumbler, the vertical beam of light in the liquid appears to change colour four times. Thus, if the selenite and Nicol are so adjusted that viewed from the west it appears blue, then from the south it will be yellow, from the east blue, and from the north yellow again. If then the selenite be removed from under the Nicol, from both west and east it will be seen as a bluish-white beam of light, while from the north and south it will be invisible altogether, as though a screen had been placed over the lens. By arranging or holding a small mirror, H, at an angle of 45°, by the side of the tumbler, the observer may see the blue colour of the beam from the west side, on which he stands, while at the same time the mirror shows him that its colour, when viewed from the north or south, is yellow. Or three mirrors may be arranged so that all four aspects of the beam may be observed at once. I do not know a more beautiful and striking way of demonstrating the properties of the polarised ray.

Experiment 4.—I now come to the most interesting of my experiments. This polarisation of all light reflected at right angles to the line of incidence is, I believe, accepted as the special characteristic of very finely-divided solid matter. I applied the test to the light upon the candle-flame. I held the Nicol in the plane at right angles to the mean path of the rays, looked through it at the soft spot of reflected sunlight, and rotated it. When the crystal crossed the line of incidence at right angles, the spot vanished; when it coincided with it, the spot was brightest. With a selenite film in addition to the Nicol prism the usual change of colour could be seen, the red and green film showing more distinctly than the blue and yellow. By using the Nicol over the eye-piece of the spectroscope I found that every part of the spectrum of the reflected sunlight is polarised alike, showing that the flame behaves with respect to light exactly as a solution containing extremely fine solid particles. I made a large number of experiments with a view to ascertain how far this similarity would hold, and I now proceed to give some of the most important.

Experiment 5.—I arranged the heliostat with the candle-flame in the focus and the spectroscope at right angles to the line of incidence, with the Nicol prism over the eye-piece, and the condenser arranged to focus the "white spot" of sunlight on the slit. I then gradually lowered the candle so as to bring the apex of the flame into the light. There was no break in the appearance of the spectrum on passing from the hot flame to the non-luminous smoke. Low down, the flame reflected only the more refrangible rays, as far as the middle of the green; towards the apex it reflected also the red. All the reflected light was polarised.

Experiment 6.—With the same arrangement as before, I turned the spectroscope so as to have the slit horizontal. I burnt some soda in the Bunsen burner at a little distance, so that the vapour from it came to the candle. The result is depicted in Fig. 2. The continuous spectrum of the inner flame is crossed by the bright sodium lines which project a little distance beyond it on either side to the limits of the outer flame. In the centre is a bright band, the spectrum of the sunlight on the flame, and on this all the Frauenhofer lines, *including the D lines perfectly black*, as in my drawing. It was very curious to see the two ends of the sodium lines standing out bright against the dark background on either side, visible still as bright lines, though faintly, upon the flame itself, up to the band of sunlight, and then strongly reversed by contrast with its greater brilliancy. I believe I am the first who has succeeded in reversing the sodium lines by reflection. It requires a bright sun to do this; otherwise the red end of the spectrum is not strong enough, but I have succeeded in showing it to several friends.

Experiment 7.—With the same arrangement, substituting a spirit-lamp charged with soda for the candle, nothing was visible to the naked eye; the flame seemed

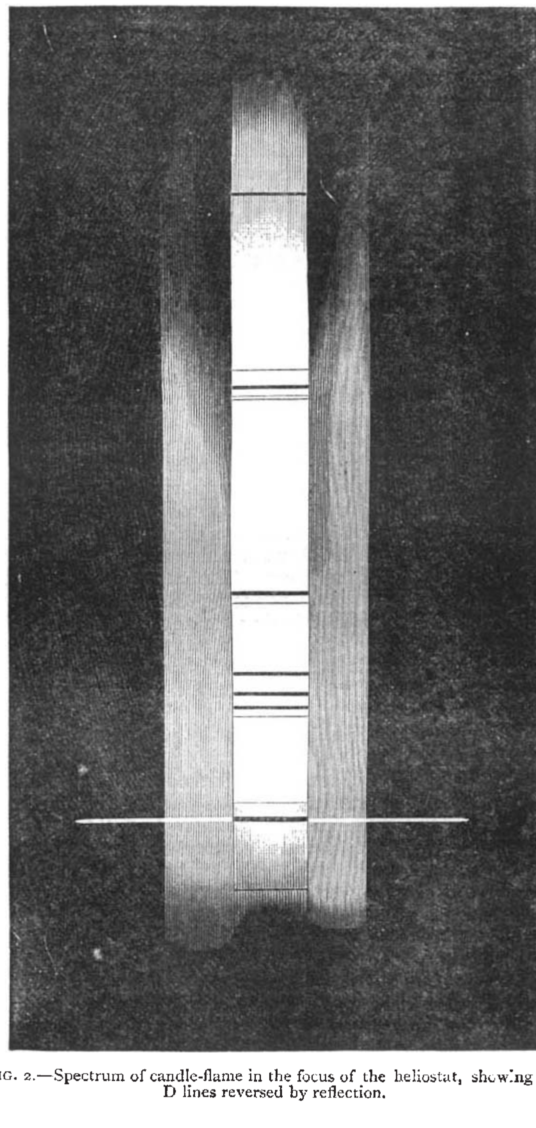


FIG. 2.—Spectrum of candle-flame in the focus of the heliostat, showing the D lines reversed by reflection.

to vanish in the glare; only in the spectroscope the bright lines were seen unaltered. With the Bunsen a brightly illuminated column of dust was seen rushing out of the tube, each particle vanishing as it reached the perfectly invisible flame, and was burnt. Several substances, *e.g.* copper oxide, and ammonium molybdate, give in the outer flame a spectrum which in my small instrument appears continuous, though lacking the "hard" look of the spectrum of an incandescent solid. But they give *no reflection* with the strongest sunlight, behaving as true vapours. It will be observed that, though I have

shown that a substance capable of emitting light of *all* wave-lengths may be capable of reflecting at the same time light of *any* wave-length, yet I have not been able to show whether or not a substance emitting light of one definite wave-length may not be able to reflect light of that same wave-length, though I have proved that it can reflect no other. For instance, the light given by sodium is absent from that of the sun, so that my experiment proves nothing with regard to it; yet that particular light is not transmitted through hot sodium vapour, but is stopped by it. One would think it must either be reflected or its energy must be used up in some way on the vapour itself. I have been unable to get access to the electric light, and no other light I know is strong enough for this experiment. I have wished also to try whether sodium burnt under pressure, or at a very high temperature, would or would not have the power of reflecting light; but in this direction I am again stopped by lack of apparatus.

Experiment 8.—The spectrum of the light transmitted through the lac solution is complementary to that reflected by it, *i.e.* the reflected light is bluish, and the transmitted yellowish-brown; in the latter case the spectrum is weakened towards the violet, and in the former towards the red. I desired to see if this was so with flame. I arranged a metallic screen with a slit one-fourth of an inch long and one-twentieth wide, close to the candle, so that all light falling upon the spectroscope must first have passed through the luminous portion of the flame, and then with a mirror directed the sunlight into the instrument. Pure sunlight was thrown into the upper half of the field for comparison, by means of the reflecting prism. Having adjusted the light so that no difference could be detected between the upper and lower halves of the field of view, the candle was placed in position in front of the slit. There was a very definite general absorption, most noticeable in those rays that are deficient in lamplight, especially about F and G, where also the spectrum of the reflected sunlight is brightest. The experiment is difficult owing to the necessity of reducing the brilliancy of the sunlight without so far reducing the angle of the illuminating ray that the hot air-currents may vitiate the result. But after many trials I satisfied myself that the more refrangible rays of light transmitted through a luminous flame are to some extent absorbed, the effect being stronger in proportion as the smoky part of the flame is approached.

Experiment 9.—It seemed evident that the reflection of the sunlight from the flame was due to its superior intensity; I therefore judged that, if I could lower the temperature of the carbon somewhat, I might get a visible reflection with light from other sources. I held an iron nail in the flame, and focused on the resulting smoke the light from a petroleum lamp. The spot of light was plainly visible, only not of a bluish white as with sunlight, but of a dirty yellow colour. It could be seen not only on the cold smoke, but also where it was of a bright cherry red; beyond that it became lost against the brightness of the incandescence. But the smoke, whether hot or cold, polarised the light exactly as the fine precipitates did.

Experiment 10.—In order to get rid of the disturbing effects of the light from the candle itself, I punched a hole in the middle of a tin plate, and placed it over the candle. The column of smoke coming up through the hole completely polarised the light thrown on it, whether from a lamp or from the sun, at right angles to the line of incidence. I then placed a little tuft of asbestos saturated with melted paraffin upon the hot plate. It gave off a dense smoke, indistinguishable to the eye from that of the burning candle. On applying the spectroscope, however, the difference was manifest. The light reflected by it was *not polarised*. I would therefore suggest that this polarisation test be the distinction between "steam," however dense, and a true "smoke." I have reason to believe that a polarising smoke only arises where the heat causes decomposition.

Experiment 11.—I placed the under side of the tin plate in the light, and found that the soot upon it reflected plane-polarised light in all directions at right angles to the line of incidence.

I now desired to ascertain if this power of reflecting light is confined to substances burning in the inner flame. It is difficult to make accurate observations as to the spectrum of the inner flame with an ordinary Bunsen burner, from the fact that it is completely surrounded by the outer flame; and this last, being but feebly luminous, gives only a very faint spectrum. I wished to make an arrangement by which the spectra of the two flames could be completely separated, while at the same time their intensity should be increased. Accordingly, I made a Bunsen burner with a rectilinear aperture, two inches long by an eighth of an inch wide, in place of the usual round tube. This gave me a broad flat flame, the edges of which I allowed to play each against a piece of well-annealed glass, so that I could look through the glass and see the flame edgeways. In this way I got a very strong spectrum of both the inner and the outer flames, perfectly distinct from each other, the ends of the flame being cut off by playing against the glass. The inner flame with its bright lines was thus completely separated from the outer with its soft, apparently continuous, spectrum: under sufficient pressure, the separation extended to the eighth of an inch or more. I could see no lines across this intervening space, except perhaps that in the violet: as to which I am not quite sure. Of the others I am certain, and I think the space is perfectly dark. As the glasses soon crack, I substituted another arrangement, which I hope still farther to perfect. In this flame I burnt a number of substances, keeping the image of the sun upon it all the while, and having the spectroscope with polarising prism, &c., arranged as in Experiment 5. I here give the results of two of the most interesting of these experiments.

Experiment 12.—I burnt on a piece of wire a mixture of copper sulphate and ammonium chloride. This compound, as is well known, gives a very beautiful and complex spectrum. When the mixture is held in the inner flame it turns dark, bubbles up, and burns like a piece of pitch, giving a continuous spectrum; and upon this flame, which never passes beyond the inner flame, the reflection of the sunlight may be seen and the Fraunhofer lines distinguished. There is also, at the same time, in addition to the beautiful blue-violet coloration of the outer flame, a curious "red smoke" right on the outer edge of it. But though in a dark room this looks far more like a solid precipitate, or true smoke, than the bright flame—though by daylight it looks so "smoky" that I thought it surely must give what I sought, a reflection in the outer flame—yet the sunlight passes through it without the slightest effect, save that it renders it invisible. The spectrum of this apparent smoke consists of groups of lines in the red.[1]

Experiment 13.—I now sought a substance that should be volatile in the inner flame and give a non-volatile oxide in the outer. I placed some zinc, which I found to be the most manageable metal for this purpose, in a small iron cup in the very centre of the flame. As soon as it boiled, flashes of white light appeared in the outer flame, and I was enabled to ascertain that these flashes gave a continuous spectrum and were also capable of reflecting sunlight, the reflected light being polarised, as in the other cases, in all directions at right angles to the line of incidence.

[1] In a recent experiment this "red smoke" gave a "soft" continuous spectrum from the extreme red to the yellow a little beyond D. It is very transient, and seems to be produced when the fused mass is drawn nearly out of the flame.

I venture to think, therefore, that the proof is fairly complete that the luminosity of a candle or gas flame proceeds from incandescent matter in a state of extremely fine division, because—

(*A*) Light can be reflected from it in the same way as from very fine particles of lac, sulphur, &c.

(*B*) The reflection begins with the violet rays when the precipitate first forms, and extends to the red as it becomes denser in the upper smoky part of the flame, the spectrum undergoing a similar change to that of the acidulated hyposulphite solution.

(*C*) There is no break in the phenomena from the commencement of incandescence to the cooling smoke and even the cold soot itself. The reflection is visibly produced by any rays, whether of the sun or from a lamp, that are more intense than those of the incandescent body; and I imagine that light that is less intense is still reflected, though it cannot be discerned.

(*D*) The spectrum of light transmitted through a flame is complementary to that reflected from it, as is also the case with a solution containing fine particles.

(*E*) The peculiar property of polarising all light reflected at right angles to the line of incidence which is considered the test of solid matter in extremely fine division is possessed by all flames giving what is known as the "solid" spectrum.

(*F*) Whenever a precipitate is actually formed by a reaction known to take place in either inner or outer flame, the resulting luminous flame has the optical properties described in this paper. Thus zinc, which produces these results only in the outer flame, gives evidence of the solidity of its oxide in the form of smoke. And with the mixture of copper sulphate and ammonium chloride it is not that part of the flame that looks most like smoke to the eye, but that which gives a "hard" continuous spectrum which is found capable of reflecting light.

I am still working on the lines indicated by these experiments, and though the foregoing is all I feel justified in publishing at present, it by no means contains all the suggestive results I have obtained in my endeavour to ascertain the cause of luminosity in gases and substances vaporised in the Bunsen flame. My time is very much occupied and my appliances limited: it may be long before I can complete my researches, so I have thought it well to make public my conclusions, so far as they go.

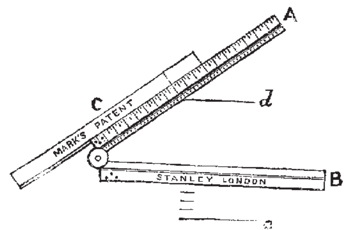
GEORGE J. BURCH

A LINE-DIVIDER

GALILEO'S proportional compasses are said to date from the year 1597. We infer that the instrument consisted of two arms, jointed, as in the accompanying figure, so that one arm could move freely about the joint. Each arm had a number of equal divisions (not necessarily of the same length on each arm), the zero point being at the joint. To divide a given length into five equal parts it is necessary to take an ordinary pair of compasses and measure the given length with these, then set the proportional compasses so that the fifth division on each arm may be at the given distance apart, then transfer with the ordinary compasses the distance between the unit divisions—this will be one-fifth of the given line. This seems to have been the manner of using the instrument employed by Galileo (cf. Marie, *Histoire des Sciences Mathématiques et Physiques*, tome iii. p. 108). Other modes of using will doubtless occur to most of our readers. The principle involved in this and similar instruments, and certainly in the one before us, is that of the proportionality of corresponding sides in similar triangles.

Our figure represents Miss Marks's patent line-divider for dividing any space into a number of equal parts. A B forms a hinged rule with a firm joint; each limb is ten inches in length (in the specimen we are describing), the limb B is bevelled, fronted with brass, and presents a straight edge, so that straight lines can be drawn along it. The limb A is also bevelled, and is divided on the bevelled edge and also on the top into eighty equal parts, so that we are enabled to divide a given length into any number of equal parts from two to eighty. A is fitted to slide in an undercut groove upon the plain rule C, which has a single line marked upon it, and is also provided with needle points on the under-side, to prevent it from slipping when placed in any position.

Suppose we take the case already considered. Slide C along A till the C line coincides with one of the lines on A, against which is the number 50. Place the corresponding line on the level of A on one end of the line to be



divided, then open out or close up the rule till the bevel of B passes through the other end of the line. Now press the points on the underside of C firmly into the paper, and slide A up till the number 4 on the line of reference is coincident with the line on C, and mark the point where the bevel of B meets the given line to be divided. Continue to move A up one division at a time till the whole line is divided. If we require lines to be drawn through the several points of division in a given constant direction, it is obvious that we must fix the instrument so that the bevel of B shall be initially in the given direction.

We have said enough to show how the divider is used, and it remains only to state that it appears to be a very handy instrument for architects, engineers, and practical drawing. Stanley, of Great Turnstile, Holborn, is the maker.

UNIVERSAL TIME AND THE RAILWAYS

ONE of the reasons why the Prime Meridian Conference met at Washington was that the United States possesses the greatest longitudinal extension of any country traversed by railway and telegraph lines, and it is quite in keeping with the spirit of American institutions that some of the most important measures necessary to carry out the resolutions of the Conference were taken by the railway men before the scientific men had begun their sittings. The action of the railway companies began as far back as 1883. It was a regular rebellion against the inconvenience of having more than half a hundred standards of railway time from east to west of the continent. At the Conference itself, Mr. W. F. Allen, one of the United States delegates, who has from the first taken the greatest interest in this special branch of the subject, brought the matter prominently before the Congress, stating what had been done. Since the Conference met, the suggestions primarily due to the railway authorities have been accepted by the Army Signal Corps and other public bodies, and from the east of Canada to the Pacific the Continent is now divided into five sections, each with its time standard, differing by one hour from those to the east and west. Thus we have Intercolonial time, Eastern time, Central time, Mountain time, and Pacific time, representing differences of one hour or 15° of longitude. We append a map, and a paper by Mr. Allen, which we have received